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Rank order difference analysis applied to tests of the television consistency index

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SUMMARY

An outline of statistical theory concerned with rank order analysis is given, and the Television Consistency Index method of assessing lamps for colour television scene lighting is described. An assessment, in terms of rank order, is made which shows that to a large extent the Consistency Index is representative of lamp performance, while being independent of particular colour television camera analysis characteristics. This work is based on a theoretical model of a colour television transmission system. The work described is part of a programme being carried out under the auspices of the Commission Internationale de l'Eclairage (CIE), who intend to complement this and other theoretical studies with practical tests before reaching a decision on the acceptability of the Television Consistency Index as a method of lamp assessment.

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RANK ORDER DIFFERENCE ANALYSIS APPLIED TO TESTS OF THE TELEVISION CONSISTENCY INDEX

E. W. Taylor, M.A.(Cantab.), C.Eng., M.I.E.E.

1. Introduction

In the field of television scene lighting, the use of incandescent (tungsten) lamps is still almost universal in studio work, except for some "follow-spot" applications where a high-intensity discharge lamp is used. The principal reason for this is the ease with which tungsten lamps can be controlled, as compared with other lamp types. High-intensity discharge lamps, for example, take an appreciable time (say one minute) to "warm-up" to their correct operating temperature, and therefore to the correct chromaticity of their light output. The starting process can often be noisy, as a high-voltage discharge has to be applied, particularly if the lamps are already hot. At present the dependence of lamp chromaticity on operating temperature precludes control of light output simply by varying the power supplied to the lamp: this effect appears however to have been appreciably reduced in some new types of discharge lamp, at least over a limited range of intensity control. Fluorescent lamps do not suffer from these defects: they can be readily started and their chromaticity is largely independent of input power. In this case the disadvantage lies in the fact that such lamps are very "broad" or diffuse sources and cannot be used to obtain the modelling effects that are an essential part of lighting for artistic purposes.

The foregoing factors lead to the conclusion that if discharge lamps are to be used for television studio scene lighting, they will have to be of the high-intensity type, since only this type can provide a concentrated source and one type of lamp should be used throughout the studio. Such lamps will have to be ignited silently some time before they are required, and thereafter their output will have to be controlled by iris or shutter mechanisms. Even so, it may still prove advantageous to use discharge lamps for studio lighting, since their efficacy (the fraction of electrical power that is turned into visible radiation) can be up to six times that of tungsten lamps. The more complex lighting operation that would be involved could probably be readily accommodated in a "computer controlled" system. The problem would remain of assessing the colorimetric effect of the use of such lamps on the reproduction of studio scenes, particularly when scenes from a studio using high-intensity discharge lamps were to be intercut with scenes illuminated with conventional tungsten lamps. The "Television Consistency Index"[1] is intended to provide a simple "yardstick" or figure of merit for this purpose, which can be used by both lamp manufacturers and lamp users when considering lamps as light sources for television scene illumination. In this respect it fulfils the same function in the field of colour reproduction by a television system as that of the CIE (Commission Internationale de l'Eclairage) Colour Rendering Index in the field of the direct visual observation of coloured objects.

The CIE is currently investigating methods of indexing lamps in terms of their suitability as light sources in various fields of colour reproduction, and the Television Consistency Index is being considered as the method to be adopted in the field of colour television. Before this Index can be recommended as a method of assessing light sources in terms of their suitability for television scene lighting, it has to be clearly established that the index values obtained do indeed give a reliable indication of this property. The principal obstacle to a ready acceptance of the Consistency Index method is that the effect of using different light sources for television scene illumination is influenced to some extent by other parameters of the television system, of which the most important is the colour analysis characteristics of the camera which is in use. As the calculation of the Consistency Index (see Section 3) is made using a mathematical model of a colour television channel, which incorporates a set of camera colour analysis characteristics, this implies that index values calculated using one set of camera characteristics will differ somewhat from corresponding values (i.e. referring to the same lamps) using another set of characteristics. The question then arises: do the index values depend so strongly on the camera analysis characteristics that the index values obtained using one camera have no relevance to the values which would be obtained using another camera, or, alternatively, is the influence of the camera analysis characteristics rather weak, so that tests on the lamps conducted using one camera may be directly applied when another camera is used. This question does not arise in the case of the CIE Colour Rendering Index, as a standard colour sensing model (the human eye as exemplified by the "CIE standard observer") is involved in this case. It would clearly be of great benefit if a similar concept could be used in the case of the Television

Consistency Index. This would however only be possible if the index values prove to be reasonably independent of the camera analysis characteristics, so that a "reference" set of camera characteristics could be used in Consistency Index calculations without the need to have knowledge of the actual camera characteristics which might be used in practice. In fact, television cameras of broadcast standard can at present be divided into two categories: the "narrow-red" category in which the response of the red colour-separation channel is restricted to below about 650 nm by the characteristics of some lead-oxide camera tubes, and the "extended-red" category which is not subject to this criterion. When the idea of a Consistency Index was first put forward[1] only the narrow-red category of camera was generally available and a reference analysis having a similar restriction in the response of the red channel was devised. More recently cameras in the extended-red category have become available and these now represent present-day practice. For this reason only extended-red practical cameras and an appropriate extended-red reference analysis have been considered in the present work (see Section 4) in which the influence of the camera analysis characteristics on Consistency Index values is being examined.

It is clear that some statistical process is required to assess the degree to which camera analysis characteristics affect Consistency Index values. Conventional regression analysis will indicate the degree of certainty with which the index values obtained using one camera can be used to predict values which would be obtained using another camera. Using regression analysis, upper and lower bounds can be calculated, within which the predicted value will fall with a given probability. Work in this field is being carried out in the Netherlands by J. J. Opstelten[2] and in Australia by Powell[3]: in addition, the author of this Report is studying a form of non-linear regression which may match the observed scatter of Consistency Index values more closely than linear regression. An important aspect of the use of the Television Consistency Index, however, is the ability to order or "rank" a number of lamps in terms of their suitability for use in television scene lighting. This aspect is of particular importance to lamp users (such as the BBC) who may in future be involved in making decisions on which one of a number of lamps to use in a studio. The dependence of the index on the particular camera in use could give rise to the situation in which the order of merit of a number of lamps differed from camera to camera. The answer to the question as to whether the influence of the camera does or does not affect the general validity of the use of the Consistency Index now hinges on whether the rank orders of lamp suitability, in terms of Consistency Index value, do or do not differ significantly from camera to camera. Rank order analysis, as discussed in Section 2 of this Report, provides a method of assessing the significance of these rank order differences. The details of the method of carrying out the rank order comparisons are discussed on Sections 4 and 5. It should be emphasized that the CIE has not yet accepted the Television Consistency Index as the method to be used for indexing lamps in the field of television lighting, as the tests on the behaviour of the Index are not yet complete: in particular, tests are still required on the behaviour of the Index when presented with practical lamp spectral power distributions, and on the correlation between calculated index values and subjective observations under test conditions representing present-day operational practice.

2. Theory of Rank Order Difference Analysis

The theory underlying the rank order difference analysis used in this Report is best approached by considering a particular example. Suppose that four lamps (L_1, L_2, L_3 and L_4) are being assessed for their suitability for use in colour television scene lighting. Television Consistency Index values are calculated using in turn three camera analysis characteristics A_1, A_2 and A_3. The results shown in Table 1 are obtained.

Table 1—Examples of Consistency Index values for different lamps and camera analysis characteristics

Camera Analysis	Lamp			
	L_1	L_2	L_3	L_4
A_1	67	78	73	62
A_2	72	75	68	62
A_3	65	72	75	69

A measure is required of the confidence with which the rank order obtained using one set of camera characteristics can be used to predict the rank order that would be obtained using another set of characteristics. With such information, the question as to whether or not the Consistency Index may be regarded as an indication of lamp performance applicable to all three cameras may then be answered.

The first step is to set down the rank orders given to the lamps using in turn each camera analysis. These rank orders are shown in Table 2. It can be seen that two lamps (L_1 and L_3) are assigned different ranks using each camera analysis characteristic, while the other two lamps (L_2 and L_4) are given the same rank order for two of the camera analyses (A_1 and A_2) but a different rank order for analysis A_3.

Table 2—Rank Orders derived from Consistency Index values shown in Table 1

Camera Analysis	Lamp			
	L_1	L_2	L_3	L_4
A_1	3	1	2	4
A_2	2	1	3	4
A_3	4	2	1	3

The next step in rank order analysis can be approached in the present case, where only a small number of items are being ranked, by considering all the possible rank orders. It may first be noted that the case of two index values being the same, so that the corresponding lamps have equal rank order, is not considered at this stage. Column 1 of Table 3 shows all these possible rank orders. The number of ways (W) of arranging N items is given by

$$W = N! \qquad \ldots (1)$$

and so there are $4! = 24$ possible rank orders.

Now consider making comparisons between two rank orders. The total number of possible

Table 3—Principles of rank order difference analysis

Rank Orders (Note 1)				Rank Order Difference Analysis (Notes 1 and 2)								
				Modulus of Rank Order Difference				Square of Rank Order Difference				Sum of Squares of Rank Order Difference (Difference Coefficient, Δ)
L_1	L_2	L_3	L_4	L_1	L_2	L_3	L_4	L_1	L_2	L_3	L_4	
1	2	3	4	0	0	0	0	0	0	0	0	0
1	2	4	3	0	0	1	1	0	0	1	1	2
1	3	2	4	0	1	1	0	0	1	1	0	2
2	1	3	4	1	1	0	0	1	1	0	0	2
2	1	4	3	1	1	1	1	1	1	1	1	4
1	3	4	2	0	1	1	2	0	1	1	4	6
1	4	2	3	0	2	1	1	0	4	1	1	6
2	3	1	4	1	1	2	0	1	1	4	0	6
3	1	2	4	2	1	1	0	4	1	1	0	6
1	4	3	2	0	2	0	2	0	4	0	4	8
3	2	1	4	2	0	2	0	4	0	4	0	8
2	4	1	3	1	2	2	1	1	4	4	1	10
3	1	4	2	2	1	1	2	4	1	1	4	10
2	3	4	1	1	1	1	3	1	1	1	9	12
4	1	2	3	3	1	1	1	9	1	1	1	12
2	4	3	1	1	2	0	3	1	4	0	9	14
3	2	4	1	2	0	1	3	4	0	1	9	14
4	1	3	2	3	1	0	2	9	1	0	4	14
4	2	1	3	3	0	2	1	9	0	4	1	14
3	4	1	2	2	2	2	2	4	4	4	4	16
3	4	2	1	2	2	1	3	4	4	1	9	18
4	2	3	1	3	0	0	3	9	0	0	9	18
4	3	1	2	3	1	2	2	9	1	4	4	18
4	3	2	1	3	1	1	3	9	1	1	9	20

Note 1. Except in Column 13, all quantities in the body of the Table refer to the lamp shown at the head of the column.

Note 2. Rank order difference analysis is between the rank order in Columns 1–4 and the rank order $L_1 = 1$, $L_2 = 2$, $L_3 = 3$, $L_4 = 4$.

comparisons is obtained by taking in turn each rank order in Columns 1–4 of Table 3 and comparing it with an arbitrary but fixed rank order. For simplicity this "comparison" rank order will be taken as the series of ascending natural numbers (in other words, the first line in Columns 1–4 of Table 3). In making each comparison, the difference is taken (Columns 5–8 of Table 3) between the rank numbers given to lamp L_1 in the two rank orders being compared, the rank numbers given to lamp L_2 in the two rank orders, and so on: these differences are then squared (Columns 9–12 of Table 3) and the sum of the squares taken (Column 13 of Table 3) to form the "difference coefficient" Δ. In general terms

$$\Delta = (a - p)^2 + (b - q)^2 + (c - r)^2 + (d - s)^2 \qquad \ldots (2)$$

where *abcd* and *pqrs* are the rank orders under comparison: in the present case *a*, *b*, *c* and *d* are the rank orders in each row of Columns 1–4 of Table 1, while *p*, *q*, *r* and *s* take the values 1, 2, 3 and 4 respectively.

The set of 24 difference coefficient values shown in Column 13 of Table 1 may now be examined. It may first be noted that all values are even: in fact, this behaviour is quite general and occurs irrespective of the number of items in the rank order. In the second place, it will be seen that some values of Δ occur more frequently than others. The value zero only occurs when the two rank orders under comparison are the same (first row of Table 3). The greatest value of Δ is 20 and this also occurs only once, when one rank order is the reverse of the other (last row of Table 3). All the (even) values of Δ between these two extremes occur at least once: the number of rank order comparisons giving rise to each such value is shown in the second row of Table 4. The third row of this Table shows the cumulative distribution of the Δ-values, or in other words the number of rank order comparisons for which the difference coefficient is less than or equal to the value shown in the first row of the Table. The distribution of the rank order comparisons between the difference coefficient values, and the cumulative distribution of these values, are also shown in Figs. 1 and 2 respectively. It can be seen that the distribution of rank order comparisons is symmetrical about the median value (10) of the difference coefficient. Furthermore, although the distribution is rather irregular, there is an underlying tendency (shown by the dashed line in Fig. 1) for it to rise to a maximum value at the median Δ-value: this tendency is much more apparent when rank order comparisons involving more than four items are considered.

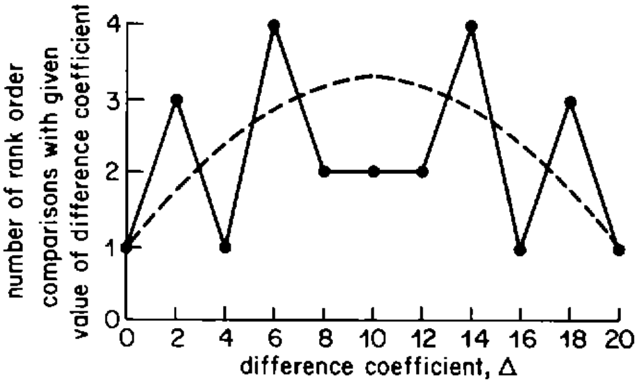

Fig. 1—Distribution of rank order comparisons between difference coefficient values

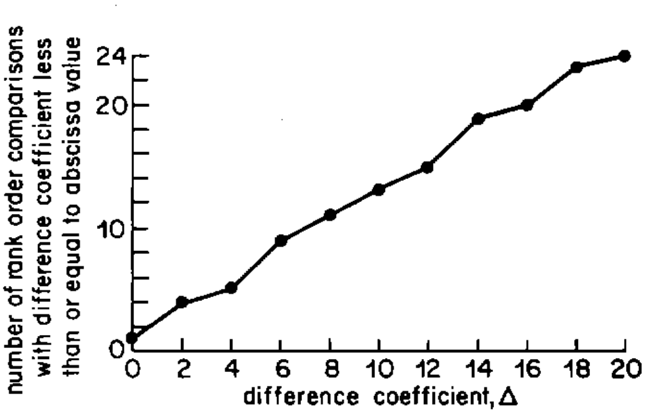

Fig. 2—Cumulative distribution of rank order comparisons between difference coefficient values

The cumulative distribution of Δ-values shown in the third row of Table 4, and in Fig. 2, may be interpreted in terms of the probability of a difference coefficient being less than or equal to its actual value purely by chance, assuming that the rank

Table 4—Distribution and cumulative distribution of difference coefficient values

Difference Coefficient, Δ	0	2	4	6	8	10	12	14	16	18	20
Number of rank order comparisons for given Δ	1	3	1	4	2	2	2	4	1	3	1
Number of rank order comparisons for Δ ≤ given value	1	4	5	9	11	13	15	19	20	23	24

orders themselves occur randomly. For example, nine out of a total of 24 possible rank order differences give rise to difference coefficient values less than or equal to six. The probability that a difference coefficient value will lie within the range 0–6 purely by chance is therefore $\frac{9}{24} = \frac{3}{8}$. (Since the difference coefficient can only take the values of the even integers, this is the same as saying that there is a probability of $\frac{3}{8}$ that the difference coefficient value will be less than eight, purely by chance: this terminology has been used in earlier work). The second row of Table 5, and Fig. 3, show the data of the third row of Table 4 and of Fig. 2 interpreted in this way. It should be noted that only the points shown in Fig. 3 have any significance, because of the restriction on the values of the difference coefficients to the even integers. It is also possible to express the probability that difference coefficients will by chance be greater than or equal to a given value: clearly such a probability decreases with increase in the difference coefficient value, as shown in the third row of Table 5.

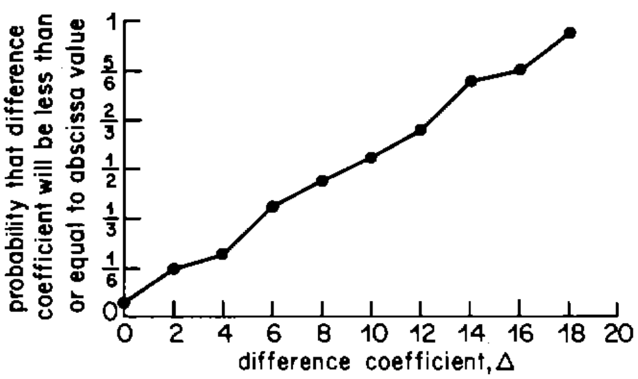

Fig. 3—Cumulative probability of occurrence of difference coefficient values

Table 5—Difference coefficient probabilities, for four items in each rank order

Difference Coefficient		0	2	4	6	8	10	12	14	16	18	20
Under assumption of mutual randomness	Probability that Δ ≤ stated value	$\frac{1}{24}$	$\frac{1}{6}$	$\frac{5}{24}$	$\frac{3}{8}$	$\frac{11}{24}$	$\frac{13}{24}$	$\frac{5}{8}$	$\frac{19}{24}$	$\frac{5}{6}$	$\frac{23}{24}$	1
	Probability that Δ ≥ stated value	1	$\frac{23}{24}$	$\frac{5}{6}$	$\frac{19}{24}$	$\frac{5}{8}$	$\frac{13}{24}$	$\frac{11}{24}$	$\frac{3}{8}$	$\frac{5}{24}$	$\frac{1}{6}$	$\frac{1}{24}$

The cumulative probability distributions of the occurrence of difference coefficient values, shown in Table 5, can now be used to provide the required numerical indication of the confidence with which one rank order shown in Table 2 may be predicted from another. In statistical terms, the hypothesis is set up that the two rank orders are mutually random, or in other words have occurred purely by chance without any causal connection between them. If the truth of this hypothesis is established, then it may fairly be said that one of the rank orders under consideration would have provided a totally unreliable agent for predicting the other rank order. On the other hand, if the hypothesis is proved to be false, then it may be said that since the two rank orders are not mutually random, there must in fact be a causal connection between them. In these circumstances one rank order would provide a reliable method of predicting the other one.

An example may make this proposition clearer. Suppose that the two rank orders were in fact the same so that the value of the difference coefficient was zero. The third row of Table 5 shows that there is a $\frac{23}{24} = 0.958$ probability that mutually random rank orders would give difference coefficients greater than or equal to the value 2. Thus there is only a $(1 - 0.958) = 0.042$ probability (see second row of Table 5) that the difference coefficient value of zero would have occurred, if the two rank orders under consideration had been mutually random (remember that only even integer values of difference coefficient exist). Under these circumstances the hypothesis that the two rank orders are mutually random may be rejected, and thus one rank order may in turn be regarded as a reliable agent for predicting the other.

The question now arises of choosing a suitable "limiting" value of difference coefficient for testing the truth or falsehood of the hypothesis discussed above. In the example quoted it was tacitly assumed that a probability of 0.042 represented such a rare occurrence that the hypothesis could be regarded as false. A widely-used "confidence limit" postulates that an event which occurs with a probability of 0.05 or less may be regarded in this way. Thus in the above example the assumption that the hypothesis was false was justified on these terms.

The rank orders shown in Table 2 may now be analysed in terms of the confidence limit discussed above. The value of difference coefficient is first calculated for each comparison of two rank orders, using the procedure described in Table 3. Column 2 of Table 6 shows the difference coefficient values (Δ_c) obtained when the rank orders shown in Table 2 are compared. Table 5 can now be used to find the probabilities that difference coefficient values less than or equal to these calculated values would have occurred "by chance" (i.e. on the assumption that the two rank orders under consideration were mutually random). Finally the confidence limit that the probability should be 0.05 or less to disprove the hypothesis that the rank orders were mutually random can be applied. It can be seen that none of the probability values shown in Column 3 of Table 6 serve to disprove this hypothesis, and therefore that all the rank orders shown in Table 2 must be interpreted as being mutually random. This in turn means that one rank order in a pair may not be regarded as a reliable agent for predicting the other. In this Report two such rank orders, which do not deviate significantly from mutual randomness, are described as "differing significantly" from each other. In fact, Table 5 shows that the two members of every pair of rank orders consisting of four items would be regarded as being significantly different unless the rank orders were identical (i.e. $\Delta = 0$). As will be seen later, this limitation does not apply when higher numbers of items are ranked.

It is interesting to examine briefly the concept of there being a "casual connection" between one rank order and another. In the first place the same set of lamps is involved in calculating the two rank orders. Thus this factor might be expected to act as an "ordering agent" in producing two rank orders which are not mutually random. On the other hand different camera analysis characteristics are used in the calculation of the two rank orders. Thus the camera analysis characteristics may be regarded as the "randomizing agent", which acts so as to produce two rank orders which are mutually random. When the difference coefficient is examined, the relative influences of the ordering and randomizing agents may be observed. A difference coefficient less than the appropriate limiting value indicates that the ordering agent (the lamps) predominated or in other words that the Television Consistency Index provides a measure of lamp performance which is in statistical terms independent of the camera analyses used to calculate the two rank orders. Thus under these conditions a high degree of confidence could be placed on the prediction of one lamp rank order from another. A difference coefficient greater than or equal to the limiting value indicates that the converse is true and that the camera analysis plays a significant part in determining the rank order.

It is perhaps worth observing that the numerical measure of confidence as given by the difference-coefficient value is useful by itself in deciding in relative terms the effect of different sets of camera analysis characteristics in Consistency Index calculations, without invoking the statistical analysis described above. For example, comparisons can be made between the use of a "reference" set of camera characteristics (see Section 1) and the use of the characteristics of a number of practical cameras. If the numerical measure of confidence is no greater when comparing the use of any of the practical cameras with the use of the reference analysis than it is when comparing the use of one practical camera with another, then it may be said that the reference camera analysis represents the practical cameras at least as well as one practical camera represents another. This was the approach adopted in early work on the interpretation of Consistency Index results. What is ultimately required, however, is the absolute measure of confidence provided by the statistical analysis, so that the question may be answered whether or not the influence of camera analysis on Consistency Index value is or is not small enough to permit the Index to be regarded as representative of lamp performance irrespective of the camera characteristic used.

The analysis presented in Section 4 of this Report involves rank orders containing seven, nine and 63 items. In the first two cases the number of possible rank orders are 7! and 9! (5040 and 36,2880) respectively. The probability of a difference coefficient being less than or equal to any particular value (within the possible range of values that the coefficient can adopt, as determined by the number of items in the rank orders) may be found by a process identical to the example involving rank

Camera analyses under comparison	Calculated difference coefficient values	Probability that value of $\Delta \leqslant \Delta_C$ would have occurred by chance
A_1 and A_2	2	$\frac{1}{6} = 0.1667$
A_2 and A_3	10	$\frac{13}{24} = 0.5417$
A_1 and A_3	4	$\frac{5}{24} = 0.2083$

Table 6—Probabilities associated with rank order data shown in Table 2

orders of four items discussed above. This process has been carried out in the theoretical analysis of rank order differences given by Kendall[4]. Because of the much larger numbers of possible rank orders, Kendall's data shows that non-zero difference coefficients may occur which are less than the limiting value given by the "5% probability" criterion. Kendall also found that as the number of items in the rank orders increased, the irregularities in the probability relationship for the difference coefficient values (see Fig. 3) became smaller, and could be adequately represented by a smooth curve if the number of items exceeded 13. He showed that in such cases the required difference–coefficient probability may be found by first calculating "Spearman's coefficient of rank correlation" (ρ), where

$$\rho = 1 - \frac{6\Delta}{N^3 - N} \qquad \ldots(3)$$

and then calculating the "Student-t" value (t), where

$$t = \rho \left(\frac{N-2}{1-\rho^2}\right)^{1/2} \qquad \ldots(4)$$

The probability of obtaining, at random, a lower value of Δ than the value under consideration is then given by the single-tailed probability corresponding to the t-value obtained from Equation 4, using the table of t-values for N-2 degrees of freedom. The limiting value of Δ required for the present analysis has been found by changing the subjects of Equations 3 and 4 to Δ and ρ respectively and solving the resulting relationships for $N = 63$ and a value of t corresponding to a single-tailed probability of 0.05 for 61 degrees of freedom. Table 7 shows the limiting difference coefficient values in the three cases under consideration.

In preliminary work on rank order differences carried out before the adoption of the present technique based on Kendall's theoretical treatment of the subject, the standard deviation of the rank order difference (σ) was used as a convenient "figure of merit". It can be seen that since

$$\sigma = \left(\frac{\Delta}{N-1}\right)^{1/2} \qquad \ldots(5)$$

it is possible to derive a limiting value of σ from a knowledge of the number of items in the rank order and the limiting value of the difference coefficient. These limiting values of standard deviation are also shown in Table 7 and are used in the discussion given in Section 4 of this Report.

It is worth examining briefly the extent of the actual differences in rank order that are regarded as not being significant using the "5% probability" criterion. This can most conveniently be done by expressing these differences in diagrammatic form. Consider, for example, the case of rank orders containing seven items. The two rank orders under comparison may be written one under the other, the items being arranged so that the upper rank order is in the natural numerical order, and changes in rank order may be made more apparent by joining equivalent rank orders with straight lines. Figs. 4a–4e give examples, using this convention, of rank order differences which are considered "not significantly different". It can be seen that one item can be moved up (or down) four places (Fig. 4a); one item can be moved up three places and another item moved down three places (Figs. 4b and 4c); or two items can each be moved down two places and two other items moved up two places (Figs. 4d and 4e). Rank order differences less extreme than those shown in Figs. 4a–4e are also of course permissible. The differences in rank order that are stated by statistical theory to be insignificant do in fact appear at first sight to be rather larger than might intuitively be expected. This point is elaborated further in Section 4.2.2 of this Report.

A factor which rank order differences analysis fails to detect is the absolute values of the Consistency Indices. Thus it is possible, for example, that while the use of two camera analysis characteristics in Consistency Index calculations give no

Number of items in rank order	Limiting values	
	Difference coefficient	Standard deviation of rank order difference
7	18	1.73
9	50	2.50
63	32,940	23.05

Table 7—Limiting values of difference coefficient and standard deviation of rank order difference

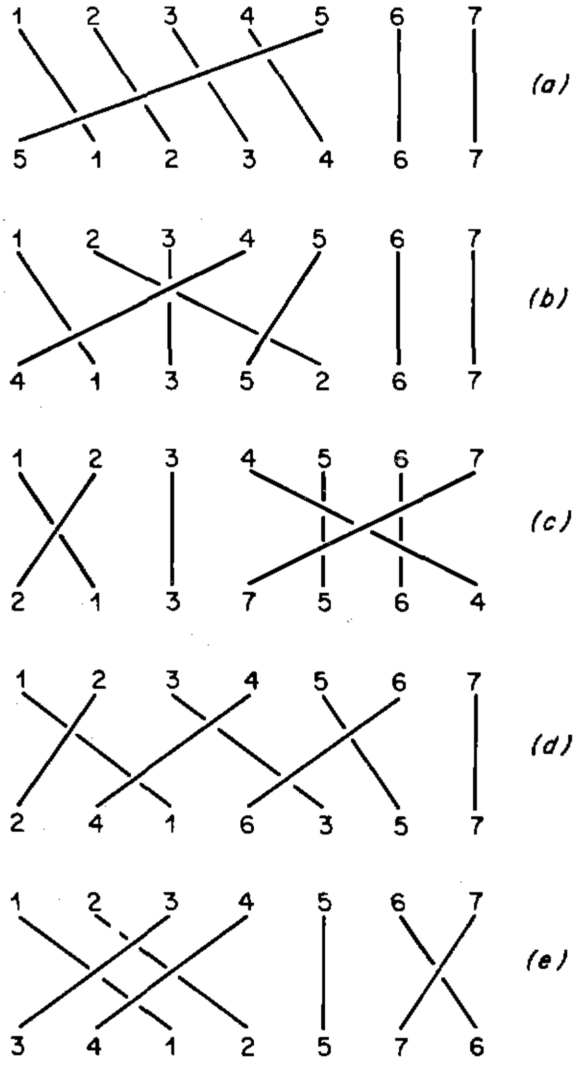

Fig. 4—Examples of pairs of rank orders which are not significantly different

(a) Largest difference four places
(b), (c) Largest difference three places
(d), (e) Largest difference two places

significant difference in the corresponding rank orders, nevertheless the Index value for any given lamp may always be higher when using one set of camera characteristics than when using the other. This situation would reveal that one camera had a greater "tolerance" for different lamps than the other, which might well be of interest when attempting to choose one camera rather than another to equip a studio. As far as lamps are concerned, however, no significant difference in the behaviour of the two cameras would be indicated. This is the factor of importance in the present context, where the use of the Consistency Index as a measure of lamp performance is under investigation: other factors in Consistency Index behaviour, such as given in the preceding example, may well be of practical interest but are not directly relevant in the present context.

3. Calculation of the Television Consistency Index

In the calculation of the Television Consistency Index, a set of test colours is assumed to be reproduced by a television system under two conditions: first with the test colours illuminated by the lamp under test as shown on the right of Fig. 5, and then with the colours illuminated by a "reference" illuminant as shown on the left of the Figure. In each case the television system is balanced (i.e. the relative gains of the colour separation channels are adjusted) so that achromatic scene objects are reproduced with the chromaticity of the display white point. Following the procedure originally proposed for the calculation of the CIE Colour Rendering Index[6] the results of the two conditions of reproduction are compared, colour by colour, using a "colour difference" formula. The Colour Rendering Index was originally formulated in terms of the 1964 U*V*W colour difference formula[7] in which the colour difference ΔE_i for the i^th^ test colour is given by

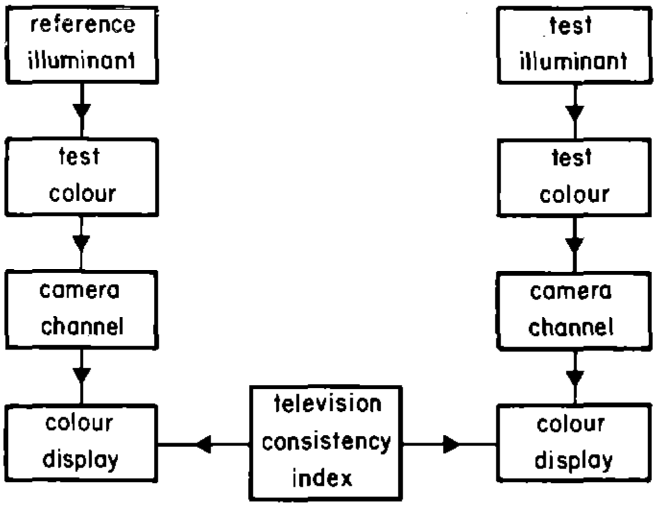

Fig. 5—Block diagram showing the method of calculation of the Television Consistency Index

$$\Delta E_i = [(U^*_{Ri} - U^*_{Ti})^2 + (V^*_{Ri} - V^*_{Ti})^2 + (W^*_{Ri} - W^*_{Ti})^2]^{1/2} \qquad \ldots(6)$$

where

$$W^*_{Ri} = 25Y_{Ri}^{1/3} - 17; \quad W^*_{Ti} = 25Y_{Ti}^{1/3} - 17 \qquad \ldots(7)$$

$$U^*_{Ri} = 13W^*_{Ri}(u_{Ri} - u_w); \quad U^*_{Ti} = 13W^*_{Ti}(u_{Ti} - u_w) \qquad \ldots(8)$$

$$V^*_{Ri} = 13W^*_{Ri}(v_{Ri} - v_w); \quad V^*_{Ti} = 13W^*_{Ti}(v_{Ti} - v_w) \qquad \ldots(9)$$

Y_{Ri} and Y_{Ti} are the luminance values of the reproduced test colour, expressed as a percentage relative to peak white, using the reference illuminant and the test illuminant respectively;

(u_{Ri}, v_{Ri}) and (u_{Ti}, v_{Ti}) are the 1960 CIE/UCS (uniform chromaticity scale) chromaticity coordinates of the reproduced colour using the reference illuminant and the test illuminant respectively;

(u_w, v_w) are the chromaticity coordinates of the display white point.

More recently the CIE has recommended two new colour-difference formulae, one of which (the CIELUV 1976 formula[8]) replaces the 1964 U*V*W* formula. In terms of the CIELUV 1976 formula Equations 7, 8 and 9 become

$$W^*_{Ri} = 116(Y_{Ri}/Y_w)^{1/3} - 16; \qquad W^*_{Ti} = 116(Y_{Ti}/Y_w)^{1/3} - 16 \qquad \ldots(7a)$$

$$U^*_{Ri} = 13W^*_{Ri}(u'_{Ri} - u'_w); \qquad U^*_{Ti} = 13W^*_{Ti}(u'_{Ti} - u'_w) \qquad \ldots(8a)$$

$$V^*_{Ri} = 13W^*_{Ri}(v'_{Ri} - v'_w); \qquad V^*_{Ti} = 13W^*_{Ti}(\mathrm{v}'_{Ti} - v'_w) \qquad \ldots(9a)$$

In Equation 7a the values of Y_{Ri} and Y_{Ti} are no longer restricted to percentage values, but the reproduced luminance of white (Y_w) must be in the same units as Y_{Ri} and Y_{Ti}. In Equations 8a and 9a the chromaticity coordinates are such that $u' = u$ and $v' = 1.5v$, where u and v are again the CIE/UCS values. The values obtained using Equations 7a, 8a and 9a are again substituted into Equation 6 to determine the colour difference value. (Strictly speaking, the symbols L^*, u^* and v^* should have been used on the left-hand sides of Equations 7a, 8a and 9a respectively, in order to follow the CIE nomenclature. The symbols W^*, U^* and V^* are here retained to make the substitution into Equation 6 more apparent.)

Following the CIE recommendation, it is proposed by the SC–3.2 Television Working Party that the CIELUV 1976 formula should in future be adopted in calculating Television Consistency Indices, and the work described in this Report is based upon values using this formula. The 1964 U*V*W* formula was however used in earlier work†. In either case, the Television Consistency Index for the i^{th} test colour (R_{ti}) is given (again by analogy with the CIE Colour Rendering Index) by the expression

$$R_{ti} = 100–4.6\Delta E_i \qquad \ldots(10)$$

Following the calculation of the Television Consistency Index for each test colour, averages are taken over certain test colour sets, as described later in this Section.

In the forseeable future, tungsten lighting will continue to be used very frequently in studio applications, and it is obvious that daylight will be the normal illumination for the majority of outside events. The purpose of the Television Consistency Index therefore becomes the assessment of lamps for lighting television scenes that will most likely be intercut with (or at least be viewed very shortly before or after) other scenes which have been illuminated with either a tungsten source or with daylight. Two reference illuminants have therefore been selected: P_{3000} (a full radiator at a temperature of 3000K) to represent studio working using tungsten illumination, and RD_{65} (Reconstituted Daylight having a correlated colour temperature of 6500K) to represent outside broadcast operations. Consistency index calculations are carried out using each reference illuminant in turn, and the lamp is assessed as "studio compatible for television" or "daylight compatible for television", depending upon which reference illuminant gives the highest index value. This assessment is intended to replace the use of correlated colour temperature as a description of lamp colorimetric performance in television scene lighting applications, since "colour temperature" can be an unreliable guide in this field, particularly when the spectral power distribution of the lamp differs considerably from that of a full or "Planckian" radiator.

Following the procedure used in deriving the CIE Colour Rendering Index, an average index value is taken over a number of test colours representing the complete gamut of scene colours that can be reproduced by the television system. Because of the particular importance attached to the correct reproduction of skin tones, a second average is taken over a number of skin-tone test colours to give a "skin-tone" index. Furthermore, because the presence of one inconsistently reproduced colour in an otherwise consistently reproduced scene would have an adverse subjective effect much greater than the overall average index would suggest, the "worst" (i.e. numerically lowest) index value out of the indices obtained for the individual test colours is also quoted, together with the identifying number of the particular test colour concerned. Thus the Television Consistency Index is expressed as four numbers:

(1) Overall index

---

† No significant rank order difference has been found (under the conditions described in Section 4) between mean Indices calculated using one formula or the other.

(2) Skin-tone index

(3) Worst index

(4) Number of the test colour giving the worst index.

The set of test colours to be recommended for the calculation of the Index has not at the time of writing this Report been determined. The work discussed in Section 4 is based on an "overall" Index value taken over 25 test colours which include the eight "BBC" desaturated test colours, the eight "BBC" skin tones, the eight "CIE" desaturated colours and the "CIE" skin tone.

The television system parameters used in the calculation of Index values represent, as far as possible, current European practice. Thus an overall transfer characteristic ("gamma") of 1.2 is used, and a reference "white" of 60% reflectance. Linear matrixing is assumed to be applied to the colour-separation signals, the coefficients being determined by an optimisation process giving best colorimetric performance using the two reference illuminants. The camera analysis characteristics used in this work are discussed in Section 4.1.2.

4. Tests of the Television Consistency Index

4.1. Method of carrying out the tests

4.1.1. Outline

The method of carrying out the tests on the Television Consistency Index has been to calculate Index values under a large number of different conditions, involving different camera analyses, different lamp spectral power distributions and the two reference illuminants, and then to apply statistical analysis to the values obtained in this way to examine the effect of the use of the different conditions. Since the purpose of the tests was to find the extent to which the Television Consistency Index is a measure of lamp performance, irrespective of the characteristics of any particular colour camera, the statistical analysis has taken the form of a comparison of index values using in turn each of a number of sets of camera analysis characteristics. This Report concentrates on the rank order difference analysis as described in Section 2: other workers[2, 3] have, as mentioned in Section 2, applied regression analysis to the Index data in order to derive numerical confidence limits for differences between Index values.

4.1.2. Camera analysis characteristics

Although work has been carried out using both the narrow-red and extended-red categories of camera analysis characteristics, involving a total of 14 different sets of characteristics, the results discussed in this Report refer only to the extended-red category (see Section 1). Eight sets of measured characteristics of practical extended-red colour cameras of broadcast quality have been used to calculate Television Consistency Index values, the cameras being identified by the letters D, E, I, J, K, L, M and N. In each case the linear matrix coefficients used in the calculation were those used operationally. All the cameras were three-tube and of the conventional "RGB" type except Camera N, which was of the "wide-green" or "RYB" type. The signal processing of this type of camera is very similar to that of a four-tube ("YRGB") camera. Television Consistency Index values have also been calculated using the extended-red reference analysis (Fig. 6) in conjunction with the matrix coefficients

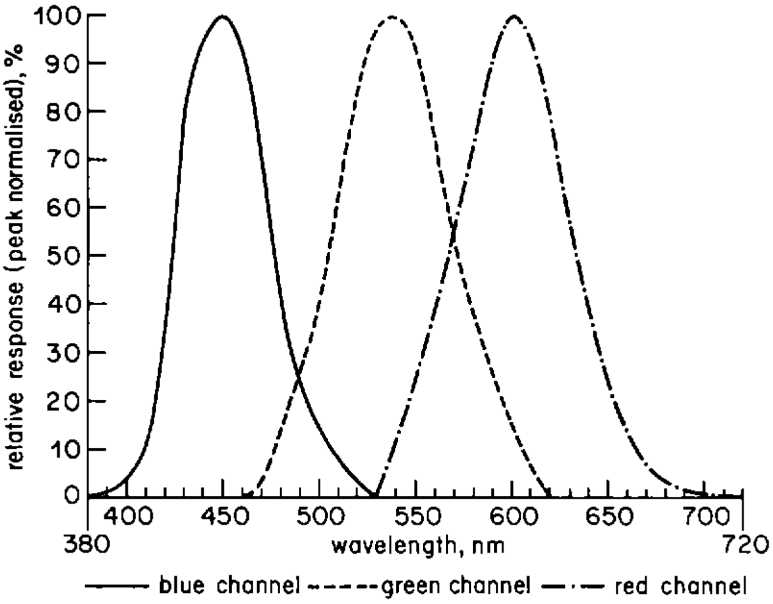

Fig. 6—Extended-red reference analysis

given by the relationship

$$\begin{bmatrix} R_{\text{out}} \\ G_{\text{out}} \\ B_{\text{out}} \end{bmatrix} = \begin{bmatrix} 1.138 & -0.175 & 0.037 \\ -0.112 & 1.151 & -0.039 \\ 0 & -0.091 & 1.091 \end{bmatrix} \begin{bmatrix} R_{\text{in}} \\ G_{\text{in}} \\ B_{\text{in}} \end{bmatrix} \quad \ldots (12)$$

4.1.3. Lamp spectral power distributions

By combining the spectral power distributions of various phosphors in the case of fluorescent lamps, or additives in the case of high-intensity discharge lamps, J. J. Opstelten has derived[9] 63 lamp spectral power distributions. Since the lamps represented by these spectral power distributions have not been constructed physically the spectral power distributions must be regarded as hypothetical and only an approximation to the actual spectral power distributions that would be obtained by the given combinations of radiating components. This is particularly true in the case of discharge lamps where the spectral power distributions of the additives are not mutually independent. Nevertheless the 63 hypothetical spectral power distributions may be regarded as typical of a large range of discharge lamps. The 63 lamps are arranged in groups or "lamp families". Each family consists of seven members having different chromaticities. The chromaticities of four members of each family correspond to full (Planckian) radiators at temperatures (or in other words have "colour temperatures") of 2600K, 3000K, 3500K and 4200K, while the chromaticities of the other three members correspond to reconstituted daylight with correlated colour temperatures of 5000K, 6500K and 8000K. There are nine families in all, designated by the letters A–I inclusive. In any one family (with the exception of Family A) the constituents of the lamp (i.e. the phosphors or additives within it) are the same, but the proportions of these constituents are varied from lamp to lamp to give the required chromaticities. Lamp family A is exceptional in not representing either a fluorescent or a high-intensity discharge lamp, but consisting of the actual full-radiator or reconstituted daylight spectral power distributions themselves.

As illustrations of these lamp spectral power distributions, Fig. 7 shows the distributions for the members of lamp families B–I inclusive having a chromaticity corresponding to a full radiator at 4200K, while Figs. 8 and 9 show the members of lamp families B and G (representing fluorescent lamps and high-intensity discharge lamps respectively) having chromaticities corresponding to full radiators at 2600K and 4200K, and reconstituted daylight having a correlated colour temperature of 8000K. These latter figures illustrate the variation with wavelength of the spectral power distribution which is required to obtain the different lamp chromaticities.

4.2. Results of the application of rank order analysis

4.2.1. Tests to determine the significance of rank order differences when using different camera analysis characteristics

As outlined in Section 4.1.1, sets of Consistency Index values have been calculated using in turn a number of different camera analysis characteristics. For each set of Index values, rank orders have been taken both in the case of each of the nine "lamp families" described in Section 4.1.3, and also over all 63 lamp spectral power distributions without regard to the lamp family structure. The rank orders obtained using pairs of cameras have then been compared. Taking the overall rank order comparisons first, Tables 8 and 9 show the standard deviations of rank order difference (see Section 2, Equation 5) obtained using pairs of camera analysis characteristics. In these Tables the relevant value is contained in the box formed by the intersection of the row referring to one camera and the column referring to the other camera. Tables 8 and 9 refer respectively to the use of P_{3000} and RD_{65} reference illuminants as described in Section 3. These rank order comparisons may now be examined using the criterion for the significance of rank order difference given in the third row of Table 7, Section 2. It can be seen that in no case did the standard deviation of rank order difference exceed the limiting value shown in Table 7, indicating that the hypothesis that the rank orders were mutually random (see Section 2) can be rejected using an even more stringent probability criterion than the "5 %" criterion used in deriving Table 7.

Turning now to the consideration of rank orders within each of the nine "lamp families", Tables 10 and 11 show the results of comparisons between the rank orders obtained using pairs of camera analysis characteristics and using P_{3000} and RD_{65} reference illuminants respectively. These tables are organised in the same way as Tables 8 and 9, except that each box now contains a column of standard deviation values. The value at the top of each column refers to lamp family A, the next value refers to lamp family B, and so on. As before, these

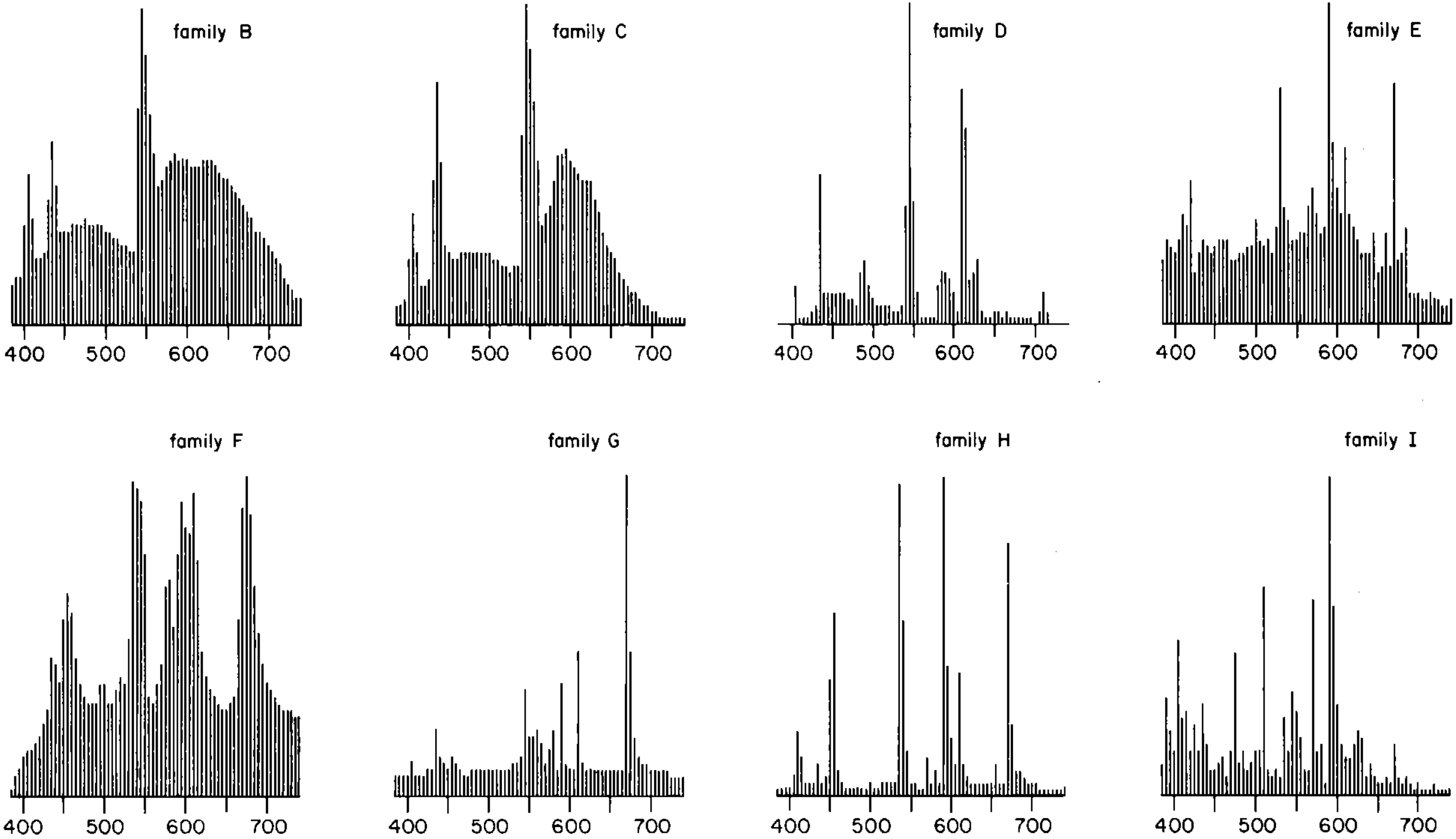

Fig. 7—Illustration of spectral power distribution of lamp families B–I

Each distribution has a colour temperature of 4200K:
Horizontal scale: wavelength (nm) Vertical scale: relative power in 5 nm wavelength range

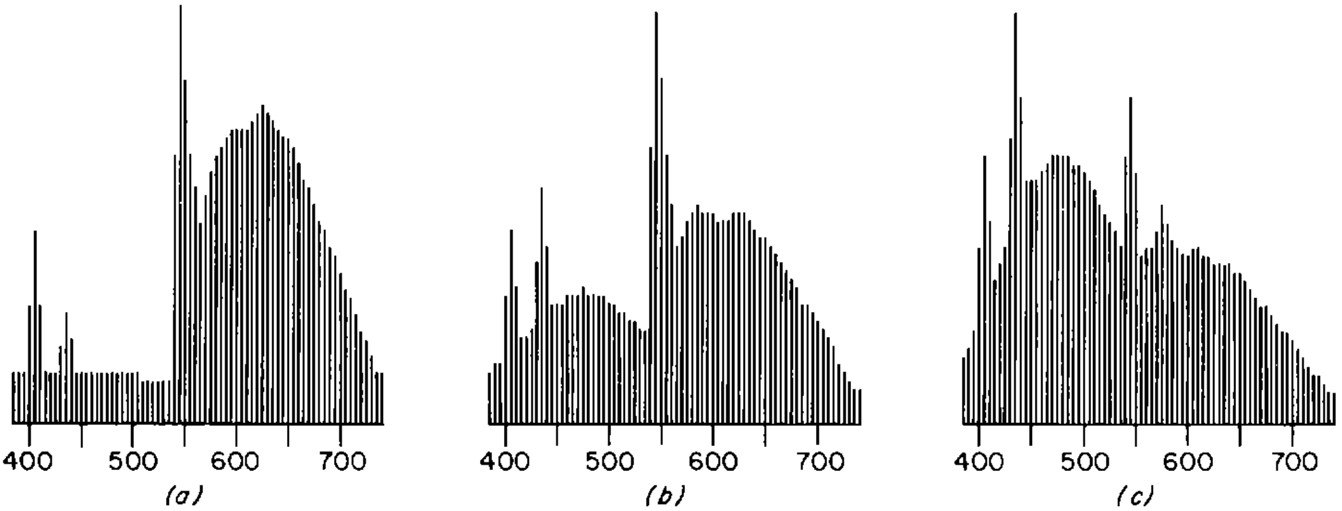

Fig. 8—Illustration of change of spectral power distribution with change of lamp chromaticity

Lamp family B (fluorescent lamp)
(a) Colour temperature 2600K (b) Colour temperature 4200K
(c) Correlated colour temperature 8000K
Horizontal scale: wavelength (nm) Vertical scale: relative power in 5 nm wavelength range

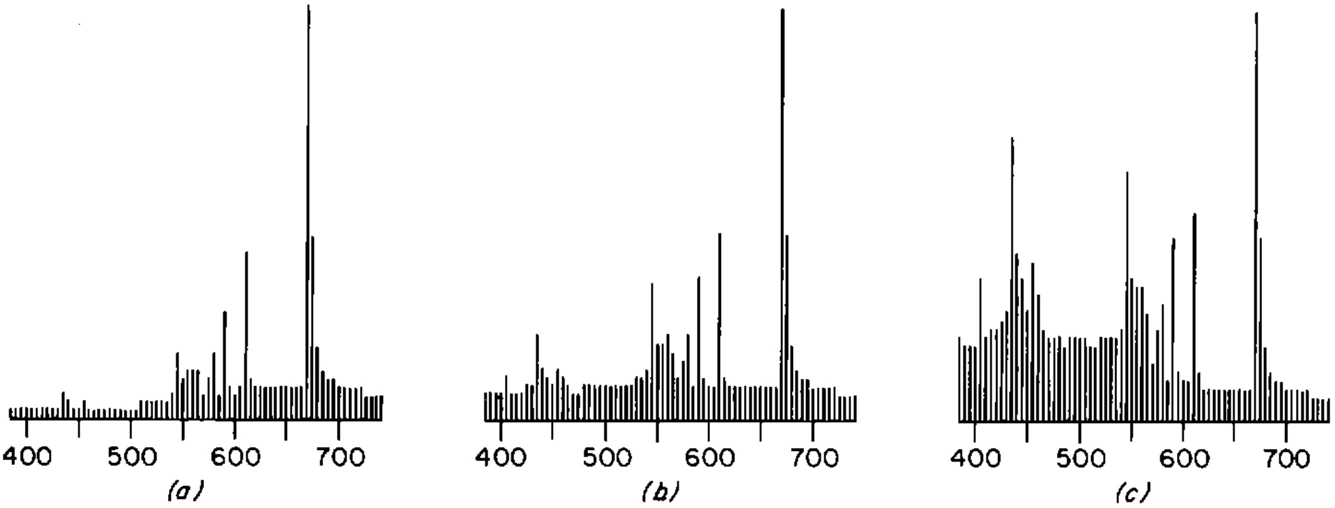

Fig. 9—Illustration of change of spectral power distribution with change of lamp chromaticity

Lamp family G (high intensity discharge lamp)
(a) Colour temperature 2600K (b) Colour temperature 4200K
(c) Correlated colour temperature 8000K
Horizontal scale: wavelength (nm) Vertical scale: relative power in 5 nm wavelength range

values may be compared with the appropriate limiting value as shown in the first row of Table 7, Section 2. Tables 12 and 13 show the lamp families for which significant rank order differences were found, again in the cases of P_{3000} and RD_{65} reference illuminants respectively, and again using the same table structure as before. These tables show that certain trends exist in the results of the rank order comparisons, as follows:

a) Significant differences are more frequent in the case of RD_{65} reference illuminant than in the case of P_{3000} reference illuminant.

b) Lamp families fall into three categories:

   i) Those which did not give rise to any significant difference in rank order, for any pair of cameras or for either reference illuminant (see families A, B, C and D).

   ii) Those which gave rise to fewer significant differences in rank order when using P_{3000} reference illuminant than when using RD_{65} reference illuminant (see families F and G, and to a lesser extent families E and I).

Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M	Camera N
5.34								
3.98	6.34							
4.47	7.18	2.97						
5.87	6.10	4.86	4.18					
5.61	5.78	4.29	3.81	2.52				
5.96	6.58	4.95	6.32	7.04	5.51			
9.26	10.79	7.15	7.37	8.88	7.67	6.10		
8.57	8.80	6.86	7.17	6.75	5.98	5.62	4.80	

Table 8—Assessments of overall rank order differences, using P_{3000} reference illuminant

Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M	Camera N
8.74								
4.91	8.70							
4.12	9.72	3.94						
5.73	10.15	5.55	3.73					
4.72	8.35	3.60	4.14	3.71				
8.70	5.08	7.39	9.68	10.72	8.03			
7.41	11.01	5.06	6.92	7.59	6.01	8.78		
7.31	9.63	6.08	7.76	7.32	5.54	7.79	4.69	

Table 9—Assessments of overall rank order differences, using RD_{65} reference illuminant

iii) Those which gave rise to fewer significant defferences in rank order when using RD_{65} reference illuminant than when using P_{3000} reference illuminant (see family H).

c) The extended-red reference analysis gives rise to no more (and often considerably fewer) significant differences of rank order when being compared with any of the practical cameras, relative to cases when one practical camera is being compared with another.

These trends are illustrated in Figs. 10 and 11, which show the distribution of significant rank order differences between lamp families and between cameras respectively. As far as the distribution between lamp families is concerned (Fig. 10) it can be seen that when using the P_{3000} reference illuminant, only lamp family H gave rise to any significant rank order differences. With the RD_{65} reference illuminant the majority of rank order differences occurred with lamp families F and G, with the addition of a few cases involving families E and I. The reasons for the association of significant rank order differences with some combinations of lamp family and reference illuminant, but not others, has not yet been determined. The rank order differences appear to be distributed fairly uniformly between the various camera analysis characteristics used in the Consistency Index calculations (Fig. 11). The reference analysis involves rather fewer significant differences than the other cameras.

Rank order difference analysis has also been carried out using the same set of camera characteristics as has been used in the work described above, but with the 63 lamp spectral power distributions

Table 10—Assessments of rank order differences, for individual lamp families, using P_{3000} reference illuminant

	Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M
Camera D	0.000 0.000 0.577 1.155 1.000 0.000 0.000 2.327 1.000							
Camera E	0.000 1.155 0.000 1.155 1.000 0.000 0.000 0.577 0.577	0.000 1.155 0.577 0.000 0.000 0.000 0.000 2.021 0.577						
Camera I	0.000 0.000 0.000 1.000 0.577 0.000 0.577 1.633 0.000	0.000 0.000 0.577 0.577 0.577 0.000 0.577 3.096 1.000	0.000 1.155 0.000 0.577 0.577 0.000 0.577 1.915 0.577					
Camera J	0.000 0.816 0.000 1.000 0.577 0.000 0.577 1.732 0.000	0.000 0.816 0.577 0.577 0.577 0.000 0.577 3.149 1.000	0.000 0.577 0.000 0.577 0.577 0.000 0.577 2.082 0.577	0.000 0.816 0.000 0.000 0.000 0.000 0.000 0.577 0.000				
Camera K	0.000 0.577 0.000 1.155 0.577 0.000 0.577 0.816 0.000	0.000 0.577 0.577 0.000 0.577 0.000 0.577 2.754 1.000	0.000 0.816 0.000 0.000 0.577 0.000 0.577 1.155 0.577	0.000 0.577 0.000 0.577 0.000 0.000 0.000 1.000 0.000	0.000 0.577 0.000 0.577 0.000 0.000 0.000 1.291 0.000			
Camera L	0.000 0.000 0.000 1.155 1.000 0.000 0.289 1.155 0.577	0.000 0.000 0.577 0.000 0.000 0.000 0.289 1.384 0.577	0.000 1.155 0.000 0.000 0.000 0.000 0.289 0.816 0.000	0.000 0.000 0.000 0.577 0.577 0.000 0.764 2.449 0.577	0.000 0.816 0.000 0.577 0.577 0.000 0.764 2.157 0.577	0.000 0.577 0.000 0.000 0.577 0.000 0.764 1.826 0.577		
Camera M	0.000 0.816 0.577 1.155 0.000 0.000 0.000 1.000 0.816	0.000 0.816 0.000 0.000 1.000 0.000 0.000 1.756 1.528	0.000 1.732 0.577 0.000 1.000 0.000 0.000 0.577 1.291	0.000 0.816 0.577 0.577 0.577 0.000 0.577 2.236 0.816	0.000 1.414 0.577 0.577 0.577 0.000 0.577 2.309 0.816	0.000 1.000 0.577 0.000 0.577 0.000 0.577 1.633 0.816	0.000 0.816 0.577 0.000 1.000 0.000 0.289 0.577 1.291	
Camera N	0.000 0.816 0.577 1.000 0.577 0.000 0.000 0.816 0.000	0.000 0.816 0.000 0.577 0.577 0.000 0.000 2.754 1.000	0.000 1.732 0.577 0.577 0.577 0.000 0.000 1.155 0.577	0.000 0.816 0.577 0.000 0.000 0.000 0.577 1.000 0.000	0.000 1.414 0.577 0.000 0.000 0.000 0.577 1.291 0.000	0.000 1.000 0.577 0.577 0.000 0.000 0.577 0.000 0.000	0.000 0.816 0.577 0.577 0.577 0.000 0.289 1.826 0.577	0.000 0.000 0.000 0.577 0.577 0.000 0.000 1.633 0.816

Table 11—Assessments of rank order differences, for individual lamp families, using RD_{65} reference illuminant

	Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M
Camera D	0.000 0.000 0.000 0.000 1.291 2.828 3.000 0.000 1.291							
Camera E	0.000 0.000 0.000 0.000 1.915 1.155 0.000 0.000 1.291	0.000 0.000 0.000 0.000 0.816 3.559 3.000 0.000 0.000						
Camera I	0.000 0.000 0.000 0.000 0.816 1.155 1.291 0.000 0.577	0.000 0.000 0.000 0.000 0.816 3.559 2.160 0.000 1.000	0.000 0.000 0.000 0.000 1.291 0.000 1.291 0.000 1.000					
Camera J	0.000 0.000 0.000 0.000 0.816 0.577 3.000 0.000 0.577	0.000 0.000 0.000 0.000 0.816 3.055 0.000 0.000 1.000	0.000 0.000 0.000 0.000 1.291 0.816 3.000 0.000 1.000	0.000 0.000 0.000 0.000 0.000 0.816 2.160 0.000 0.000				
Camera K	0.000 0.000 0.000 0.000 0.816 0.577 3.000 0.000 0.000	0.000 0.000 0.000 0.000 0.816 3.055 0.000 0.000 1.291	0.000 0.000 0.000 0.000 1.291 0.816 3.000 0.000 1.291	0.000 0.000 0.000 0.000 0.000 0.816 2.160 0.000 0.577	0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.577			
Camera L	0.000 0.000 0.000 0.000 1.915 1.633 1.291 0.577 1.291	0.000 0.000 0.000 0.000 0.814 1.414 2.160 0.577 0.000	0.000 0.000 0.000 0.000 0.000 2.582 1.291 0.577 0.000	0.000 0.000 0.000 0.000 1.291 2.582 0.000 0.577 1.000	0.000 0.000 0.000 0.000 1.291 1.915 2.160 0.577 1.000	0.000 0.000 0.000 0.000 1.291 1.915 2.160 0.577 1.291		
Camera M	0.000 0.000 0.000 0.000 1.000 1.414 0.816 1.000 0.000	0.000 0.000 0.000 0.000 0.577 3.606 3.512 1.000 1.291	0.000 0.000 0.000 0.000 1.000 0.577 0.816 1.000 1.291	0.000 0.000 0.000 0.000 0.577 0.577 1.915 1.000 0.577	0.000 0.000 0.000 0.000 0.577 1.155 3.512 1.000 0.577	0.000 0.000 0.000 0.000 0.577 1.155 3.512 1.000 0.000	0.000 0.000 0.000 0.000 1.000 2.708 1.915 0.577 1.291	
Camera N	0.000 0.000 0.000 0.000 0.816 1.633 1.633 0.000 0.816	0.000 0.000 0.000 0.000 1.732 1.414 1.915 0.000 1.915	0.000 0.000 0.000 0.000 2.380 2.582 1.633 0.000 1.915	0.000 0.000 0.000 0.000 1.414 2.582 0.577 0.000 1.000	0.000 0.000 0.000 0.000 1.414 1.915 1.915 0.000 1.000	0.000 0.000 0.000 0.000 1.414 1.915 1.915 0.000 0.816	0.000 0.000 0.000 0.000 2.380 0.000 0.577 0.577 1.915	0.000 0.000 0.000 0.000 1.433 2.708 2.236 1.000 0.816

Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M	Camera N
H								
	H							
	H	H						
	H	H						
	H							
			H	H				
			H	H				
	H							

Table 12—Distribution of significant rank order differences between lamp spectral power distributions and between cameras, using P_{3000} reference illuminant

Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M	Camera N
FG								
E	FG							
	FG							
G	F	G	G					
G	F	G	G					
E	G	F	F	FG	FG			
	FG		G	G	G	FG		
	I	EFI	F	FG	FG	EI	FG	

Table 13—Distribution of significant rank order differences between lamp spectral power distributions and between cameras, using RD_{65} reference illuminant

arranged in a different way. Seven groups of lamps have been taken, each group containing lamps of the same chromaticity taken from the nine lamp families. Thus each group contains lamps with the same visual appearance, but having spectral power distributions which differ considerably from each other. This is, perhaps, a more realistic test than the consideration of each lamp family separately: a television organisation, for example, would probably be comparing different makes of lamp, involving different principles of lamp design, and therefore having different spectral power distributions. The results of this analysis is shown in Tables 14 and 15 for the cases of P_{3000} and RD_{65} reference illumunants respectively. These values can also be compared with the appropriate limiting value as shown in the second row of Table 7, Section 2. It can then be seen that no significant differences of rank order were obtained.

4.2.2. Discussion

Taking an overall view of the results of the tests involving the extended-red camera analyses, and in particular comparing the rank orders obtained, using different camera analyses and including all 63 spd's without regard to spd family, it has been found that these rank orders do not differ significantly from each other. In other words, rank order is not significantly dependent upon

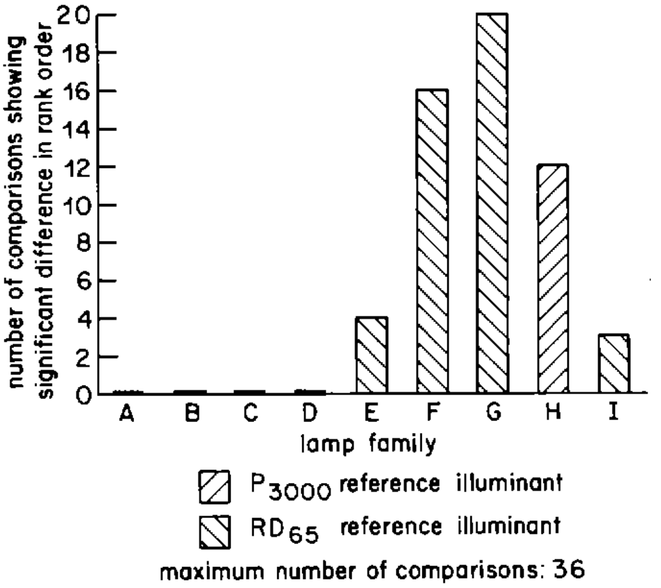

Fig 10—Distribution of significant rank order differences between lamp families

camera analysis. The criterion of significance used in this case is that there is only a 5 % probability, or less, that the two rank orders under consideration would have been as similar to each other as was found to be the case, had these two rank orders been mutually random. This is not to say that the rank orders obtained using different camera analyses will necessarily be identical or even nearly identical. Because of the immense number of possible rank orders (factorial 63), an apparently large divergence of rank order is still permitted within the 5 % probability outlined above. For example, placing the first four items of one rank order as the last four of the other order comes within the 5 % probability limit (with, however, very little change in rank order of any of the other items). The actual rank order differences obtained during the tests are well within the 5 % significance limits, and hence not so extreme as the above example, which is on the borderline of the limit.

Turning to the results obtained by comparing rank orders within lamp family, a rather more complicated detailed picture emerges. There are apparently some types of lamp spectral power distribution and some types of practical camera for which the order in which the lamps are ranked would differ significantly, both when comparing the results obtained using two practical cameras and also when comparing the use of a practical camera analysis with the use of the extended-red reference analysis. In the case of other types of lamp and camera no such significant differences occur. Furthermore, it appears that in some cases significant rank order differences are more numerous when the P_{3000} reference illuminant rather than the RD_{65} reference illuminant is involved, while in other cases the situation is reversed. Thus it seems that the representation of all practical cameras by a reference analysis may not be universally valid, the differences which do sometimes occur between rank orders obtained using reference and practical analyses reflecting the differences which exist when using one practical camera and then another. Preliminary analysis suggests, however, that in cases where the rank order analysis shows significant differences between results obtained using different camera analyses, the actual differences in consistency index value involved may be rather small, thus rendering the difference obtained of less importance than might be suggested from the rank order analysis itself. This suggestion is borne out by the results

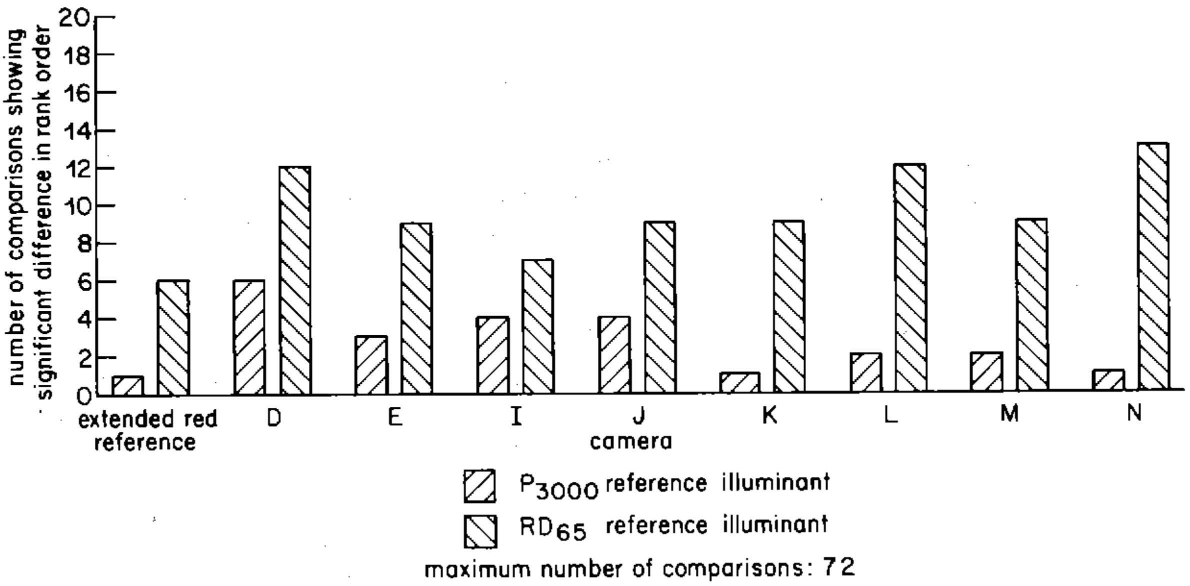

Fig. 11—Distribution of significant rank order differences between cameras

Table 14—Assessments of rank order differences, for individual "visual appearance" lamp sets, using P_{3000} reference illuminant

	Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M
Camera D	0.500 0.707 1.581 1.000 0.866 0.866 0.707							
Camera E	0.500 0.500 0.866 0.866 1.118 0.707 1.000	0.000 0.866 1.323 0.707 0.707 1.000 1.000						
Camera I	0.500 1.118 1.000 0.707 1.225 1.000 1.225	0.707 1.000 1.658 1.000 0.707 1.225 1.225	0.707 0.866 0.500 0.500 0.866 0.500 0.500					
Camera J	0.707 0.866 1.225 1.323 1.225 1.323 1.323	0.500 0.707 1.000 1.118 0.707 1.323 1.118	0.500 1.118 0.500 1.000 0.866 0.866 1.000	0.500 1.000 0.866 1.118 0.000 0.500 0.707				
Camera K	0.500 0.707 1.323 1.118 1.225 1.323 1.323	0.707 0.707 0.866 0.707 0.707 1.323 1.118	0.707 0.500 0.707 0.707 0.866 0.866 1.000	0.000 0.500 1.000 1.000 0.000 0.500 0.707	0.500 0.866 0.500 0.500 0.000 0.000 0.000			
Camera L	0.000 0.707 0.866 1.323 1.225 0.707 0.500	0.500 0.707 1.323 1.225 1.225 1.000 0.500	0.500 0.500 0.866 1.000 0.707 0.000 0.866	0.500 1.000 1.000 1.323 1.414 0.500 1.000	0.707 1.225 1.118 1.225 1.414 0.866 1.000	0.500 0.707 0.866 1.000 1.414 0.866 1.000		
Camera M	1.118 1.414 1.414 1.936 2.236 1.000 1.323	1.414 1.500 1.732 1.658 1.871 1.414 1.414	1.414 1.118 1.000 1.500 1.414 0.500 0.500	1.000 0.707 0.866 1.803 1.658 0.707 0.707	1.323 1.414 1.225 1.581 1.658 1.118 1.323	1.000 1.000 1.000 1.414 1.658 1.118 1.323	1.118 1.323 0.866 1.323 1.414 0.500 1.225	
Camera N	0.707 1.414 1.118 1.803 1.936 1.323 1.323	0.866 1.323 1.323 1.414 1.581 1.658 1.414	0.866 1.225 0.707 1.414 1.323 0.866 0.500	0.500 0.866 0.866 1.732 1.323 1.118 0.707	0.707 1.323 0.866 1.118 1.323 1.414 1.323	0.500 1.000 0.707 1.000 1.323 1.414 1.323	0.707 1.323 0.707 1.225 1.323 0.866 1.225	0.866 0.707 0.866 0.707 1.000 0.500 0.000

Table 15—Assessments of rank order differences, for individual "visual appearance" lamp sets, using RD_{65} reference illuminant

	Extended Red Reference	Camera D	Camera E	Camera I	Camera J	Camera K	Camera L	Camera M
Camera D	1.871 1.658 1.803 1.225 1.414 1.225 1.323							
Camera E	0.000 0.000 0.500 0.866 1.118 1.118 0.866	1.871 1.658 1.732 1.000 1.118 0.500 0.866						
Camera I	0.707 0.707 0.500 1.000 0.707 0.500 0.000	1.803 1.871 1.732 1.323 1.225 1.414 1.323	0.707 0.707 0.000 0.707 0.866 1.323 0.866					
Camera J	0.707 0.866 0.500 0.866 1.118 1.500 1.000	1.803 2.000 1.732 1.658 1.414 1.500 1.500	0.707 0.866 0.000 0.866 1.118 1.414 1.118	0.000 0.500 0.000 0.866 0.500 1.323 1.000				
Camera K	0.500 0.500 0.500 0.866 1.323 1.414 1.414	1.732 1.732 1.732 1.000 1.225 0.707 0.866	0.500 0.500 0.000 0.000 0.866 0.500 0.866	0.500 0.500 0.000 0.707 0.707 1.500 1.414	0.500 0.707 0.000 0.866 0.500 1.118 1.000			
Camera L	1.323 1.323 1.658 1.414 1.803 1.118 1.323	0.707 1.118 0.500 0.500 0.866 0.500 0.000	1.323 1.323 1.581 1.225 1.000 0.000 0.866	1.414 1.581 1.581 1.581 1.500 1.323 1.323	1.414 1.871 1.581 1.803 1.658 1.414 1.500	1.225 1.500 1.581 1.225 1.323 0.500 0.866		
Camera M	1.118 1.500 1.225 0.707 1.500 1.118 1.323	2.291 2.449 2.062 1.225 1.414 0.500 0.000	1.118 1.500 1.118 0.500 0.500 0.000 0.866	1.118 1.000 1.118 0.866 1.225 1.323 1.323	1.118 1.225 1.118 0.707 1.323 1.414 1.500	1.000 1.323 1.118 0.500 1.000 0.500 0.866	1.803 1.871 1.936 1.323 1.118 0.000 0.000	
Camera N	0.707 1.323 0.866 1.225 1.936 1.658 1.803	2.233 2.550 2.000 1.581 1.658 1.000 0.707	0.707 1.323 1.000 1.000 1.000 0.707 1.323	1.118 1.000 1.000 1.323 1.500 1.803 1.803	1.118 1.118 1.000 0.866 1.414 1.414 1.658	1.000 1.118 1.000 1.000 1.000 0.500 0.866	1.732 2.000 1.871 1.500 1.225 0.707 0.707	1.225 0.707 1.118 0.707 0.707 0.707 0.707

obtained using correlation techniques[2,3], which show that the calculated Consistency Index values should be regarded as "centre-points", subject to a tolerance up or down relative to the nominal value, and that lamps giving Index values which differ from each other by less than this tolerance should be regarded as being the same as regards their suitability for television scene lighting. In the present work, small differences in Consistency Index value (which could well be insignificant) have been retained, since Kendall's theory of rank order difference analysis is not well adapted to include a large proportion of equally-ranked items. This retention of small differences between Index values is likely to have increased the sensitivity of the analysis to apparent differences in rank order that would not occur in practice. Work is still in progress to determine both the numerical value of this tolerance, and also the most suitable method of expressing it so as to represent most closely the scatter of Consistency Index values observed in practice.

An analysis is also required of the causes which lead to some spectral power distributions but not others giving similar Consistency Index performance over a number of camera analyses. This could lead to a more detailed knowledge of the types of lamp (in terms of their spectral power distributions) that are and are not suitable for television scene lighting.

As implied in the footnote on page 9, work has also been carried out to compare the use of the 1964 and 1976 colour-difference formulae (see Section 3). Average Index values, over all test colours, were calculated using each formula and rank orders were derived in each case, again within lamp families and over all lamps without regard to the family structure. In no case did the rank order obtained for any camera using the 1964 colour-difference formula differ significantly from the rank order obtained for the same camera using the 1976 formula, adopting the appropriate criterion of significance shown in Table 7, Section 2. Thus it can be concluded that the choice of colour-difference formula does not significantly affect the rank order of lamps in terms of Consistency Index value.

One of the items (Camera N) in the set of practical camera analyses is of the RYB type. The signal processing in this type of television camera is closely allied to that of a four-tube (YRGB) camera. The behaviour of Camera N, in terms of the rank order analysis, did not differ noticeably from the general behaviour of other extended-red cameras. This indicates that there should be no intrinsic difficulty in representing such cameras by a "three-tube" type of reference analysis, although this conclusion should be regarded as tentative until further examples of such practical cameras have been tested.

It is worth emphasizing that identity or near-identity of results must not be expected when judging the effect of using different camera analyses in Consistency Index calculations. It is likely to prove impossible to develop a general method of categorizing lamps in terms of their suitability for television scene lighting which will not at times give results rather different from those obtained using individual practical cameras. The best that can be hoped for is that the method will give differences which are no wider than those obtained between one practical camera and another. However, it may be noted that in the cases of differences of rank order made without regard to lamp family, the standard deviation values obtained in practice are all considerably below the limiting value. This implies that, broadly speaking, a better agreement in rank order exists than is indicated by the "95% probability" criterion used to derive this limit. Thus it is likely that the extended-red reference analysis represents as good a choice of reference-analysis characteristics as it is possible to produce (at least, with regard to representing practical cameras of this type). Nevertheless, it also seems, on present evidence, that there are some types of spectral power distribution for which significant differences in rank order will inevitably occur if a reference analysis is used to represent practical cameras in Consistency Index calculations. Such differences would also occur between one practical camera and another.

As outlined in Section 3, a set of 25 test colours was used in the Consistency Index calculations described in this Report. This set of colours is probably unnecessarily large, and consideration is being given to the use of a smaller number of colours, still distributed through the television colour gamut to provide a reasonable representation of practical scene colours. Work carried out by J. J. Opstelten in connection with the Colour Rendering Index[10] suggests that the rank order of Index values is not likely to be greatly affected by a change from one such "representative" set of test colours to another.

5. Conclusions

Because of the greater efficacy of most discharge lamps, when compared with conventional incandescent (tungsten) lamps, it could prove advantageous to use such lamps for studio lighting despite the greater difficulty of controlling their light output without significantly altering their chromaticity. Discharge lamps are in any case encountered in many "outside broadcast" events. For these reasons the Television Consistency Index has been devised with the intention of providing a simple figure-of-merit by which lamps can be assessed in terms of their suitability as light sources for television scene illumination.

One use of the Consistency Index will be to place lamps in order of merit or "rank order" as far as their suitability for television scene lighting is concerned. Rank order difference analysis, as devised by Kendall[4, 5], provides one method of testing whether the Consistency Index gives a useful general indication of lamp performance in this respect, or whether, alternatively, the Index can only be held to be representative of one set of operating conditions.

The Commission Internationale de l'Eclairage (CIE) is currently investigating methods of indexing lamps in terms of their suitability as light sources in various fields of colour reproduction, and the Television Consistency Index is being considered as the method to be adopted in the field of colour television. This work is not yet completed and the CIE has not as yet recommended the Television Consistency Index (or indeed any other method) as a means of describing lamp performance in this field. The work on the Consistency Index is however far enough advanced for some likely trends in its behaviour to be discerned, particularly as revealed by the rank order difference analysis.

It appears that in general terms, over a large number of lamp spectral power distributions, the rank orders obtained using a number of different camera analysis characteristics do not differ significantly from each other. This supports the hypothesis that one "reference" camera analysis characteristic can be used to calculate a general Index that would be valid for all colour cameras of broadcast quality. However, it also appears that when some categories of lamp spectral power distribution are examined, significant differences in rank order are obtained between one camera and another. This point requires further investigation, as it could reveal types of spectral power distribution that are particularly unsuitable for television scene lighting.

"Colour temperature" or "correlated colour temperature" can prove to be a misleading method of categorizing lamps for television scene lighting, and the Television Consistency Index should provide a better alternative in this respect.

6. References

1. SPROSON, W. N. *and* TAYLOR, E. W. A colour television illuminant consistency index. BBC Research Department Report No. 1971/45.
2. OPSTELTEN, J. J. Private communication.
3. POWELL, B. Private communication.
4. KENDALL, M. G. The advanced theory of statistics, 3rd Ed., Vol. I, pp. 388–401 (see in particular Equations 16.5 and 16.26). London, Charles Griffin and Co. Ltd., 1947.
5. KENDALL, Sir Maurice. Rank correlation methods, 4th edition. Charles Griffin and Co. Ltd., London, 1975.
6. CIE. Method of measuring and specifying colour rendering properties of light sources. CIE Publication No. 13.2 (TC–3.2), 1974. Bureau Central de la CIE, Paris.
7. WYSZECKI, G. *and* STYLES, W. S. Color science. Table 6.3, Item 7, pages 460–461. John Wiley and Sons, Inc., New York.
8. CIE. Supplement No. 2 to CIE publication No. 15 (E–1.3.1) 1971/(TC–1.3), 1978. Bureau Central de la CIE, Paris.
9. OPSTELTEN, J. J. Private communication.
10. OPSTELTEN, J. J. The dependence of the general colour rendering index on the set of test colours, the standard observer and the colour-difference formula. Lighting Research and Technology, *12*, 4, (1980), pages 186–194.

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